AR-009-232

DSTO-RR-0041

The DORIC Program:
HF Modem Technology

Martin C. Gill

19960429 028

DTIC QUALITY INSPECTED 1

D E P A R T M E N T ◆ O F   D E F E N C E

DEFENCE SCIENCE AND TECHNOLOGY ORGANISATION

The DORIC Program : HF Modem Technology

Martin C Gill

Communications Division
Electronics and Surveillance Research Laboratory

DSTO-RR-0041

ABSTRACT

This report describes the HF data modem work undertaken at DSTO as part of the DORIC program.

RELEASE LIMITATION

Approved for public release

D E P A R T M E N T   O F   D E F E N C E
◆
DEFENCE SCIENCE AND TECHNOLOGY ORGANISATION

APPROVED FOR PUBLIC RELEASE

The DORIC Program : HF Modem Technology

EXECUTIVE SUMMARY

This report describes the modem development work undertaken at DSTO as part of the DORIC program. It briefly describes the nature of the HF channel and how it affects various modems, including an insight into the special requirements of adaptive modem design on the HF channel. A history of current generation modems precedes a detailed examination of the advantages offered by the DSTO HF modems. The report concludes with the future direction of the research work.

THIS PAGE IS INTENTIONALLY BLANK

Authors

Martin C Gill
Communications Division

Martin Gill graduated from the University of Adelaide
with a Bachelor of Science in 1983 and a Bachelor of
Engineering (Honours) in 1984. During 1988 he
completed a Master of Science degree at the Royal
College of Science, Shrivenham, UK. In 1991 he
completed his Graduate Diploma in Electronic Systems
from the University of South Australia. Since joining
the Defence Science and Technology Organisation in
1983, he has worked predominantly in the
communications field.

THIS PAGE IS INTENTIONALLY BLANK

Contents

1.   Introduction

Many types of traffic, particularly messages and data, are fundamentally digital in nature and comprise discrete symbols, for example characters, which can be easily represented as binary information in the form of 0's and 1's. Inexorably, there is a move towards digital transmission as this mode of transmission offers distinct advantages: high-reliability encryption, traffic integration, and the possibility of interfacing directly to computers and the information they contain. Hence the performance of digital transmission is of great importance.

Raw digital information cannot be sent over a voice band channel because a stream of pulses has a frequency spectrum which covers a very large bandwidth. To overcome this, the discrete digital bits are coded into a sequence of waveforms whose spectrum is contained within the bandwidth of the radio channel, typically a nominal 3kHz for HF (International agreements limit the bandwidth to 2700Hz). The conversion process from digital data to an analog band limited signal is performed by means of modulation in which one, or more, carrier waves have their amplitude, frequency and/or phase changed according to the data value to be transmitted.

Demodulation is the reverse of this process. It involves determining which of the possible waveforms was transmitted and mapping this choice back into digital information. This is a straightforward and well understood process when the signal is undistorted, albeit noisy. Unfortunately, HF radio channels severely distort signalling waveforms and successful transmission can only be achieved through careful signal design and sophisticated signal processing in the demodulator.

It is usual to combine a MOdulator and DEModulator (modem) into a single enclosure giving rise to the now familiar acronym for this piece of equipment.

The performance of a digital modem is determined by the number of errors that the demodulator makes for a given number of number of transmitted bits. This ratio, known as the Bit Error Rate (BER), is the fundamental measure of link performance. Digital transmission systems degrade in a different manner from their analog counterparts: unlike the gradual degradation seen in analog systems, digital systems display a threshold effect whereby as the SNR reduces below a critical point the number of errors increases rapidly. In a fading channel, this effect is observed as bursts of errors during periods of low signal strength. To overcome the effects of fading it is useful to spread a message in time to improve the probability of adequate reception. Thus, another important quality of service requirement is link delay, which for HF links typically ranges from a few tens of milliseconds up to 10 seconds. As throughput, delay and error rate can be traded off, a marginal link can often be reconfigured through dynamic adaption of the radio parameters to give satisfactory service for the desired traffic.

1.1.   Cross Reference to other sections in the DORIC report

Readers are strongly recommended to read The DORIC Program : Adaptive Radio, since the modems form the physical layer of the adaptation strategy.

1.2.   Convention

This report refers to a range of HF radio modems. The 16-tone, 39-tone and the single tone modems are described in the MIL-STD-188-110A. The modems developed by DSTO are referred to as the TCM-16, 52-tone and chirp. References to any other modems will be made clear in the text.

2.   The Adaptive Radio Modem for HF

Many factors can affect the quality of a radio link, and quite often these factors are time varying. In order to optimise the performance of radios on these real channels a modem should adapt itself to suit the current environment.

Radio modems cover a broad range of frequencies and propagation media, however once the concept of an adaptive modem is demonstrated, it can be applied to any frequency or media. The initial research concentrated on ionospheric HF radiowave propagation. This band was chosen for several reasons:

* The HF channel is one of the most challenging since it is constantly changing and suffers noise from both man-made and atmospheric sources.
* The Australian defence force has many HF assets, so any improvements have a significant impact.
* The HF channel is the only communications medium offering world-wide coverage using only defence owned and operated equipments.

Adapting a radio modem to suit the channel over which it is communicating places additional constraints on its design. It should be easy to reconfigure and changes should not severely disrupt data traffic. The initial approach was to use existing MIL-STD HF modems, unfortunately this had severe short comings:

* The measured performance of the modems was relatively poor.
* Attempts to improve the performance using applique units reduced data throughput and revealed only marginal improvement.
* Changing the modem parameters, for example increasing the bit rate, required the modem to be taken off air, reconfigured and then reconnected. This introduced an unacceptably large penalty.

Given the above considerations DSTO investigated the design and implementation of a range of modems which overcame the above shortfalls. Most importantly the modems had to offer superior performance and be capable of rapid reconfiguration with a minimum of disruption to data throughput. The method chosen was to keep the signalling waveform the same and adjust the amount of error-control coding applied to the signal.

39-tone modems. Increasing the tolerance of the parallel-tone modems would degrade their performance on channels which experience fast fading.

A disadvantage of the single-tone modem is the complexity of implementing space diversity reception. Space diversity reception gives a significant improvement in performance when data interleaving must be kept short. The high signalling rates used in the single-tone waveform requires both inputs to be fully demodulated including the computationally demanding channel equalisers. In contrast, provision of space diversity is straight-forward for parallel-tone waveforms.

2.2.   Historical Development of the DSTO Modem

A fundamental parameter for determining modem performance is the bit rate that the modem is transmitting. Put simply, the lower the bit rate, the better the modem will work in the presence of channel interference and noise. When DSTO tested several MIL-STD modems we found that the performance did not improve significantly as the bit rate was lowered indicating some fundamental flaw in their implementation.

The most significant under performance was found for the 75 bps telegraph modems, where the current MIL-STD modems require significant signal power to achieve communications. This inspired DSTO to design and implemented a 75 bps chirp modem. The design criterion was to provide robust communications in the presence of channel distortion and high levels of interference. The modem achieved reliable communications at less than 1/20th the transmit power of existing modems. The extensive use of optimum detection, interleaving and error-control coding are largely responsible for the modems outstanding performance.

While the chirp modem is very robust, the low bit rate limits its usefulness. DSTO therefore investigated higher speed modems. The initial starting point was the MIL-STD 16-tone Kineplex modem. The improvements consisted of removing the doppler tone and adding error-control coding to the waveform. A range of bit rates was implemented by adjusting the amount of error control coding applied to the signal. The resulting modem, called the TCM-16, covers bit rates from 300 to 2400 bps.

The Kineplex modem does not fully use the 2700 Hz of available bandwidth. The next development was to increase the number of tones to utilise the entire channel bandwidth. Using the tone spacing employed in the Kineplex modem results in a 24 tone modem capable of transmitting 3600 bps. In order to increase the bit rate to 4800 bps it is necessary to decrease the multipath tolerance of the modem to less than 1 msec. The multipath tolerance can be restored if the symbol length is increased, which also increases the number of tones. The chosen solution is a 52-tone modem with 2 milli-seconds of multipath tolerance, currently supporting 1200, 2400, 4800 and 7200 bps.

3. Developments employed by the DSTO HF modems

The research undertaken at DSTO has resulted in new HF modems. The program has required achieving an understanding of the strengths and weaknesses of current HF modems. The emphasis has always been to keep the design of the modems simple, reducing the vulnerability of the modems to attack.

3.1 Conquering the HF channel

Multipath propagation on the HF channel leads to signal fades. In addition the noise on HF channels is highly impulsive in nature, that is it consists of short bursts of high energy interference. Signal fading and impulsive noise significantly degrade the signal-to-noise ratio of the received signal, leading to large bursts of errors. Demodulators can reduce the number of decoder errors by introducing error-control coding and data interleaving.

3.1.1 Error-Control Coding

Errors will always occur in the transmission of digital data, however by including sufficient error control coding, modems can correct many of these errors. The effect is that for the same bit error rate the transmitter power can be reduced, the subsequent power saving is referred to as the coding gain of the code. The design of error control coding strategies has progressed rapidly in the last decade. The application of these modern schemes to HF modems has resulted in significant performance improvements.

Error-control coding has been applied to communication systems for many years. Most early schemes took the raw data stream and added extra information into the data stream. The error control decoder uses the extra bits to correct any bits that are corrupted by noise on the channel. While the separation of the error control coding from the data modulation and demodulation simplifies the conceptual design of the modem, it reduces the amount of coding gain.

Ungerboeck is credited with the early work into Trellis Coded Modulation (TCM). In this scheme the coding and modulation are combined to extract the greatest possible coding gain. One significant advantage of TCM is the ease with which soft decision decoding can be implemented, resulting in further coding gains. In addition much of the work in TCM has focused on channels which experience Additive White Gaussian Noise (AWGN). While this is a relatively accurate assumption for many channels it is not valid for HF channels. Work has been undertaken to select coding schemes that are optimised for the fading and non-Gaussian noise that is experienced on HF channels.

A final advantage of TCM is the ease of designing a family of modems which can transmit data at traditional data rates. For example the TCM-16 modem employs R =

2/3 8PSK for 2400 bps. By reducing the rate to R = 1/2 QPSK, gives a 1200 bps modem. While a further reduction to R = 1/4 QPSK, results in 600 bps.

3.1.2   Interleavers

Error-control codes are only designed to fix a relatively small number of errors. When errors occur in large bursts, they must be spread so that the error-control scheme only sees a few errors at a time. This is achieved using interleavers. The drawback with interleavers is that they introduce delay. Current MIL-STD modems allow a maximum interleave depth of 10 seconds. DSTO found that this is probably not sufficient to overcome the slow fading typically encountered on practical HF channels, therefore they have implemented up to 60 seconds of interleaving. In addition several of the modems are capable of implementing space diversity reception, which substantially improves performance without long interleaving.

Conventional interleavers read the data to be sent into a square matrix. The transmitter fills the matrix row by row and the data is transmitted column by column once the matrix is full. At the receiver the matrix is filled column by column and once full read out row by row. Since the transmitter and receiver implement the matrix the total link delay is twice the delay of the transmitter. In addition for the receiver to correctly reassemble the information it must be able to identify the first data value, which requires synchronisation.

The use of TCM allowed the DSTO range of modems to implement a different form of interleaving. In this form multiple trellis encoders and decoders are employed. At the transmitter the data sequence is passed to each of the encoders in sequence. The receiver implements the same number of decoders as encoders in the transmitter and no synchronisation is required. This greatly simplifies the implementation. In addition the interleaving delay is experienced only at the receiver, so for the same overall link delay the multiple trellis decoder interleave structure offers greater diversity.

3.1.3   HF Noise estimation

Traditional modem design has assumed that the noise encountered on the channel is Gaussian, very much like the hiss when an FM receiver is mistuned. HF channels are characterised by "cracks, pops and whistles" a clear indication that the noise is non-Gaussian. Measurements revealed that the noise is impulsive. This has a significant impact on the design of the modems.

To minimise the effects of impulsive noise the DSTO modems estimate the size of the interference. As the interference increases, the modems tend to reduce the importance of the affected information. Put simply information which is not subject to noise will be used, while heavily corrupted data will be ignored. This weighted information is then used in the error-control decoder.

In the parallel-tone modems, narrowband noise will be localised to one or two signalling tones. The noise estimators can recognise the interference as noise and

therefore reduce its effect on the modem output. As such it is significantly easier to implement narrowband excision on parallel-tone modems than on single-tone modems, where adaptive excision filters must be added before the channel equaliser.

3.2   Preambles

The MIL-STD 39-tone and single-tone modems employ a preamble sequence. The preamble is sent from the transmitter before the data transmission commences and tells the receiver the incoming data rate and interleave depth. While this greatly simplifies link establishment (since the incoming data rate is automatically selected) it also makes the modems more vulnerable. If a receiver does not receive the preamble the modem will take a long time to acquire. This is significant when simplex links are employed, for example in fleet broadcast applications, where verification that the preamble has been correctly received is not possible. If the receiver does not receive the preamble several minutes of information will be lost.

DSTO tested several commercially available single-tone modems, and noted that while "synch on data" is part of the MIL-STD, none of the modems reliably demonstrated this feature. The 39-tone modem does not employ "synch on data". Therefore neither of these modems could be recommended for variable rate no-acknowledge communications paths, unless the data traffic is interrupted on a regular basis to transmit the preamble sequence.

The DSTO range of modems does not employ preambles. Instead the modems will employ automatic modulation recognition. In this mode the modem will identify the incoming waveform and then load the appropriate modem to demodulate it. While identification of the exact depth of data interleaver is complex, DSTO feels confident that this is preferable to the inclusion of preambles and "synch on data".

3.3   4800 bps and Beyond

The trend is towards higher data rates. Fundamentally the HF channel is always going to have trouble providing sufficient bandwidth. Several options are being examined to meet the requirements of high data rate communications.

Recently work commenced to increase the data rate of the 52-tone parallel tone modem to 7200 bps. This involves further increasing the raw data rate and applying higher rate error-control codes. The result is a modem which is less robust than the existing modem, but still offers great potential. The error control codes are optimised for fading channels giving the modem similar error bursts to the lower speed modems when being used on fading or impulsive noise channels. When combined with ARQ the higher data rate between error bursts should deliver a high error free data throughput.

One researcher has simulated an uncoded 9600 bps single-tone modem. This modem should outperform the 7200 bps parallel-tone modem once some error control coding is added. Unfortunately the channel equaliser used is too computationally expensive to

implement in real time in its current form, however work will begin once the MIL-STD single-tone modem has been fully developed.

Finally using more bandwidth allows higher data rates. This can be achieved using adjacent sidebands, for example using the upper and lower sideband gives a total of 6kHz of bandwidth. Combining two 4800 bps modems gives 9600 bps, and two 7200 bps modems gives 14400 bps. Each of these modems will have similar performance to the original modem, perhaps fractionally better due to the additional frequency diversity.

3.4   Measured Performance

This section presents the performance of the DSTO modems as measured on the standard CCIR test channels. The CCIR channels simulate two paths which experience fading in the presence of AWGN. In the CCIR Good channel the two paths are separated by 0.5 msec and fade slowly at 0.1 Hz. On the CCIR Poor channel the paths are 2 msec apart and fade at 1 Hz. CCIR Good results are the most important as this is the most representative channel for the Australian region and the hardest channel in which to operate, due to the slow fading causing long periods with little input signal.

Figure 1 compares the performance of several 75 bps telegraph modems on the CCIR Good fading channel. The Bit Error Rate (BER) gives the quality of the data, so the smaller the BER the lower the number of decoder errors, for example a BER of 1.0E-4 indicates that on average 1 bit in every 10000 is decoded incorrectly. The BER is plotted against the input signal-to-noise ratio (SNR). The better the modem implementation the lower the BER for a given input SNR. Refering to figure 1, the DSTO Chirp modem achieves a BER of 1.0E-4 at a SNR of -5 dB, while the single-tone modem requires nearly 10 dB for the same BER. The difference of 15 dB is equivalent to a transmitter with 1/20th the power for the same BER.

Figures 2 to 8 give the measured performance of the TCM-16 and 52-tone HF modems. The curves show the effects of changing the data rate and the interleaving depth.
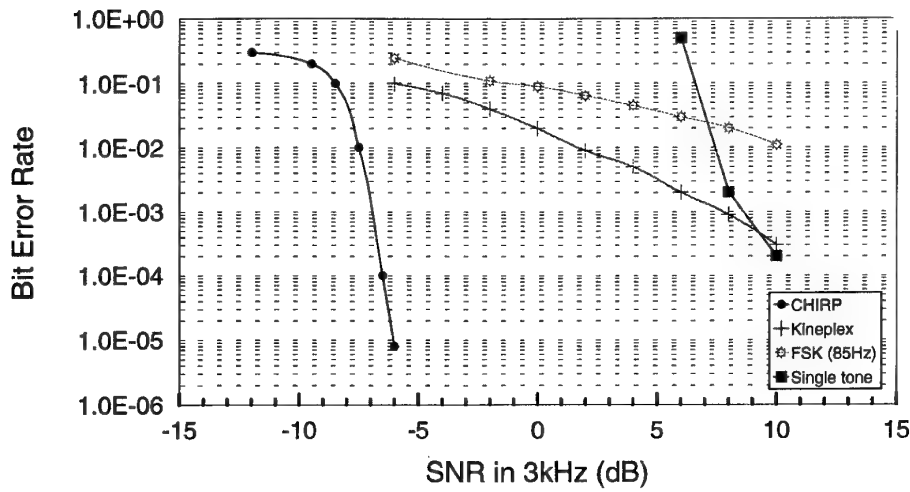
Figure 1:   *Comparison of 75 bps modems on CCIR Good channel*
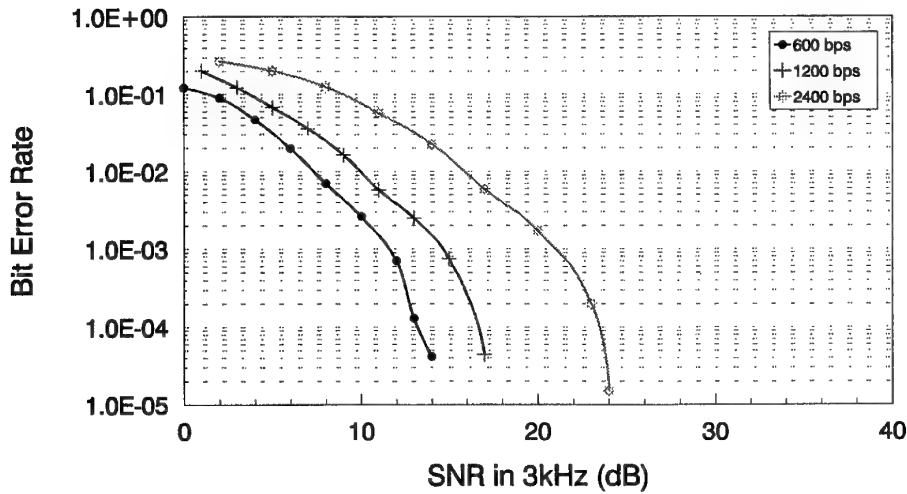
Figure 2:   *TCM-16 modem on CCIR Good channel with no interleaving*
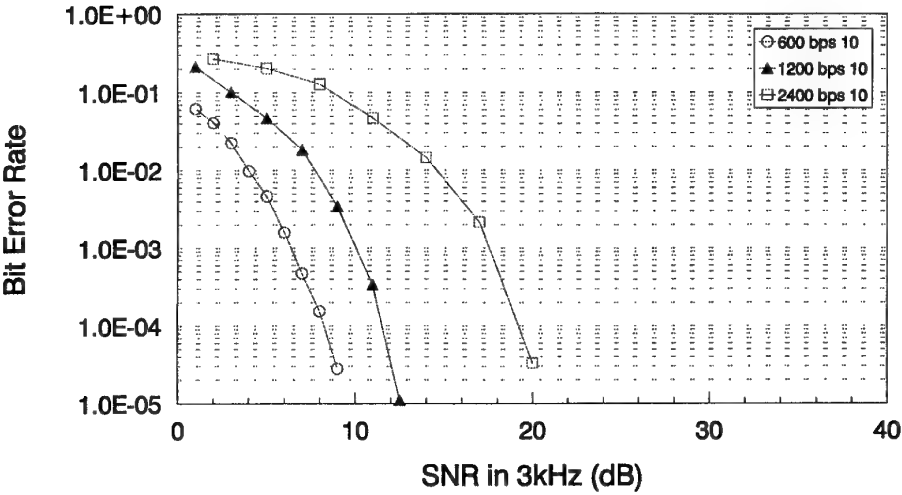
Figure 3:   *TCM-16 modem on CCIR Good channel with 10 seconds of interleaving*
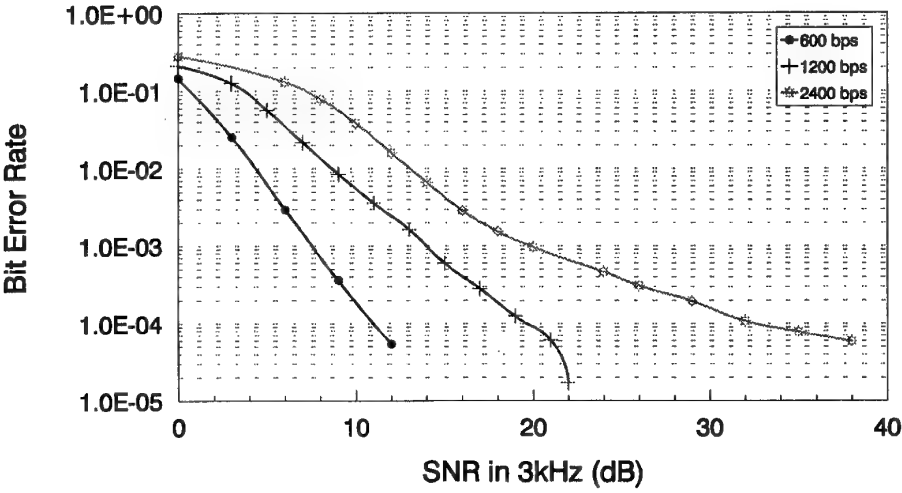
Figure 4:   *TCM-16 modem on CCIR Poor Channel with no interleaving*
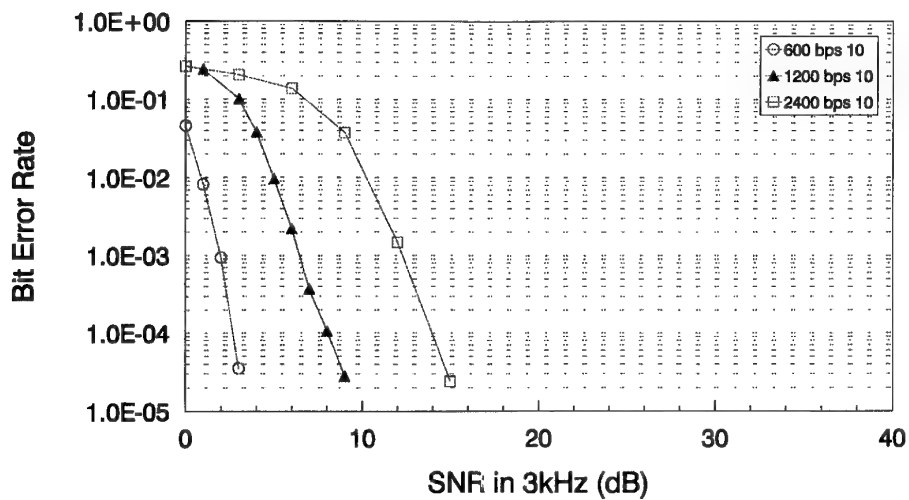
Figure 5:   *TCM-16 modem on CCIR Poor channel with 10 seconds of interleaving*
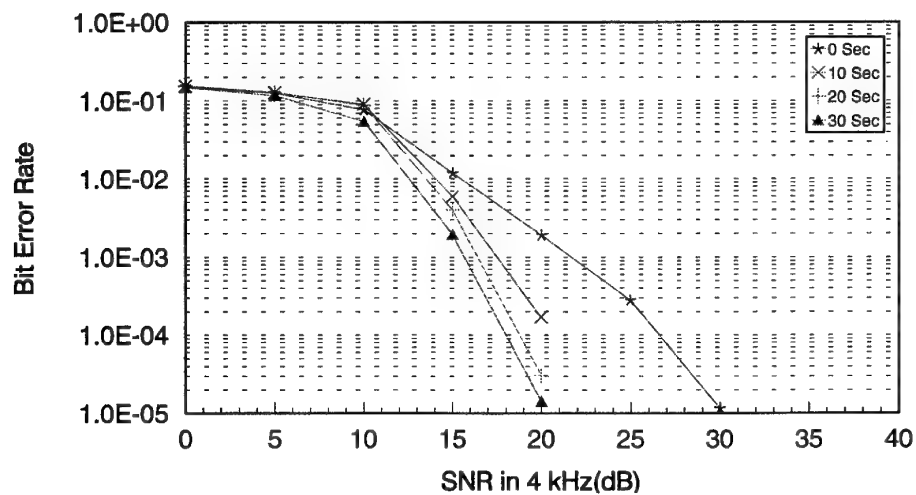
Figure 6   *4800 bps 52-tone modem on CCIR Good channel with different interleaving depths*
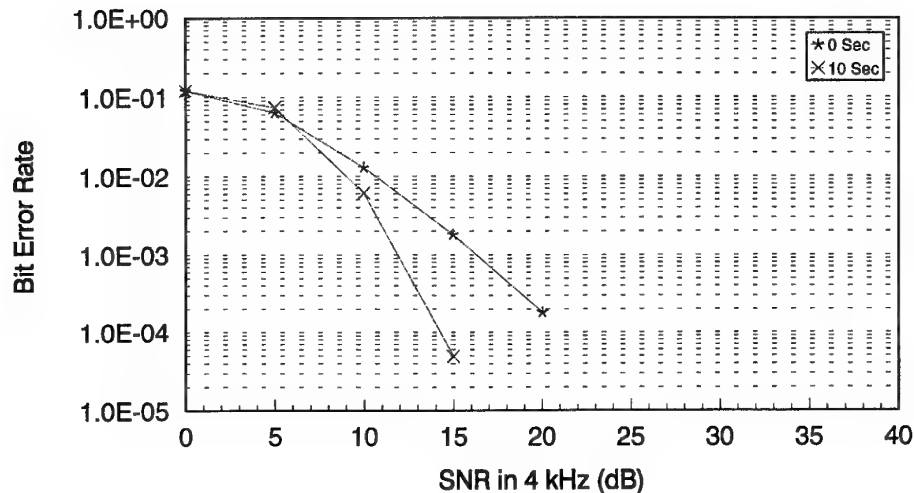
Figure 7   *2400 bps 52-tone modem on CCIR Good channel with 0 and 10 seconds of data interleaving*

Two modems can provide 2400 bps giving an overlap of data rates between modems. This has been done to simplify the implementation of rate adaption (section 4.2) and future developments in ARQ (section 4.1). It is important to note that while the 52-tone modem outperforms the TCM-16 modem on the CCIR Good channel the performance is much closer on the CCIR Poor channel. As stated the 52-tone modem performs well on channels with up to 2 msec of time delay spread and when the Doppler is less than 20 Hz, while the TCM-16 modem can tolerate 4 msec of time delay spread and closer to 50 Hz of Doppler offset.

DSTO was concerned about the multipath tolerance of the 52 tone modem so it tasked the Ionospheric Prediction Service to calculate the probability of encountering paths of equal amplitude with greater than 2 milliseconds of multipath. The IPS predicted that for single hop HF, there was almost no probability of encountering such a path, indicating that for communications within Australia the CCIR Poor test channel is not realistic. This result indicates that the 52-tone modem is viable for practical HF channels.
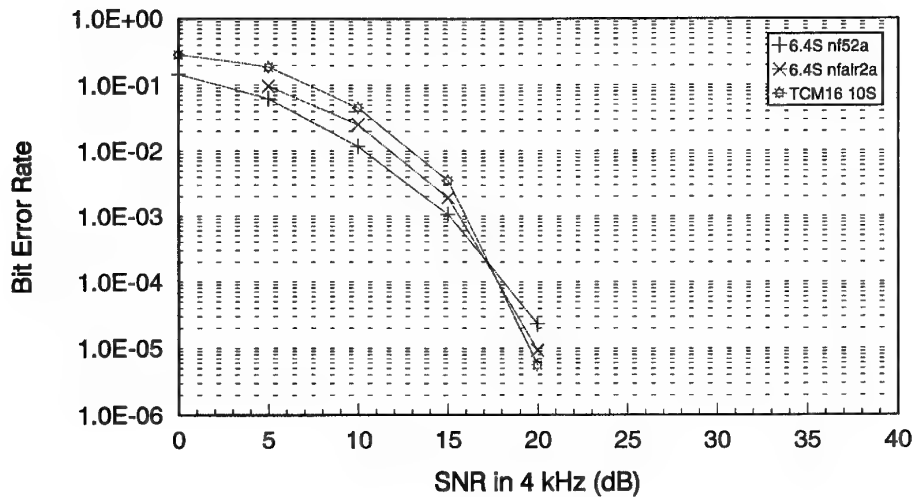
Figure 8   TCM-16 *modem on CCIR Good channel with impulsive and Gaussian noise*

Figure 8 shows the performance of the TCM-16 modem on the CCIR Good test channel. These tests differ from the previous figures in the type of noise that is added to the signal. The noise added to the modems has the same signal to noise ratio but is not Gaussain noise. Instead the noise is derived from actual measurements. Noise file 52a (nf52a) was recorded on a naval platform, while noise file air 2a (nfair2a) was recorded on a P3C aircraft. The curves show that the modem works significantly better at low signal to noise ratios than the AWGN curves. This is because of the impulsive noise excision that is employed in the modems.

3.5   Commercialisation

During 1993, GEC Marconi Systems Pty Ltd Australia signed a commercialisation assessment agreement with DSTO to evaluate the DSTO modems. The potential of the product lead GMS to sign a business agreement in April 1994 and commence the implementation of a technology demonstrator. The technology demonstrator implements the DSTO 52-tone and chirp modems. Both modems were successfully trialed on links between Adelaide and Canberra in October 1994.

The production version of the modem, referred to as the ARM 9401, will include the full range of DSTO modems, adaptive rate control and automatic modulation recognition. In addition the ARM will offer backwards compatibility with existing MIL-STD HF modems, by including the 16-tone Kineplex, 39-tone and single-tone modems as implemented by DSTO.

The current production time table will have the preproduction units available early in 1995 with full production units available later the same year.

4. Towards modem adaption

4.1   Duplex Transmission and ARQ

For the adaption strategy to be successful both ends of the link must be able to negotiate with each other. Currently the assumption is that the link will be full duplex, however the concept could be extended to half duplex at a later date. The availability of full duplex on strategic assets is taken for granted. It will become more common in the tactical environment with the introduction of the RAVEN HF radios, which can include a filter to protect the receiver from the transmitter.

The first major advantage with full duplex transmission is the availability of error free data transmission. This is possible using Automatic Repeat reQuest (ARQ). When the receiver detects an error it asks the transmitter to resend the data. For this to be successful the information must be formed into packets, where each packet carries sufficient information to identify itself and a check sum that can be used to detect the presence of errors in the transmitted packet.

Bit error rate performance curves can be misleading when testing modems on fading channels. A particular BER will consist of long sections of virtually error free transmission followed by bursts of errors. Clearly this environment is ideally suited to ARQ, where error bursts can be isolated to relatively few packets. Note that the smaller the spread of errors the better ARQ will work, therefore it the interleaving depth should be decreased to the minimum to avoid spreading error bursts. This has the added advantage that the variable link delay will be relatively short when being used over good channels.

Although ARQ is technically part of the adaption layer (The DORIC Program: Adaptive Radio), it has been included in the modem implementation. This has been done so that the ARQ scheme is an integral part of the modem signalling waveform. In a parallel tone modem the data bits are already grouped by the signalling waveform. By selecting the ARQ packet length as several complete modem frames, fading or impulsive noise will tend to introduce errors in several modem frames, so errors are localised to a small number of packets. Since the errors are localised, the ARQ scheme only has to request the retransmission of a few packets, maximising throughput.

ARQ is still in its early development stages. Much of the preliminary design work has been done using simulations of the 2400 bps TCM-16 modem on fading channels. These simulations indicate that the optimum packet size is around 400 bits, and that the modems should employ minimal interleaving. These results will need to be verified once the real time versions are fully implemented.

4.2   Costs in changing modes

As mentioned above steps have been taken to minimise the penalty of changing from one bit rate to another, however some costs still remain.

Changing the coding rate requires the error control buffers to be flushed. At this time research has not been undertaken into the exact cost of this flush. By keeping the number of interleavers the same, the new code can pick up where the previous code left off, and the burst of errors associated with the change will be minimised. While this technique should minimise data loss it will lead to variable amounts of data interleaving, which is undesirable. The alternative is to keep the amount of interleaving constant, which will result in a burst of errors while the new code initialises its error control buffers. It should be noted when using ARQ, the burst of errors associated with the change of rate will be detected and removed.

When changing from one modem to another, for example from the 52-tone to the TCM-16 modem, the signalling waveform changes. This incurs an additional penalty since the modem has to acquire the signalling waveform, however employing rapid signal acquisition significantly reduces this cost. When acquiring the signal the modem does not attempt to interpret the incoming signal only to acquire it. Current implementations takes less than ½ second to acquire the signal. The overhead of the interleaver and error-control code remain the same.

5.   Other Research Areas

5.1 Other Frequency Bands

While this report has focused on the HF modem work it should be emphasised that this is not the only radio band of interest. As stated in the introduction the intention was to tackle the complex HF channel and then transfer the solutions to other frequency bands.

5.1.1 VHF Troposcatter

An alternate beyond line of sight propagation method, requiring the use of high gain antennae at the transmit and receive end of the circuit illuminating a common volume of atmosphere. Troposcatter is useable from VHF to SHF frequencies, and gives ranges of up to 500 km. Tropoducting offers greater range but is dependent on meteorological and geographical conditions and is therefore not being considered. A possible use is to link remote tactical units into the public switched telephone network.

DSTO has established an experimental VHF troposcatter link between Berri and Adelaide. The main problem has been the lack suitable exciters and receivers. In the VHF band the majority of exciters and receivers employ frequency modulation. The

DSTO modems require SSB modulation and want to utilise the full 25 kHz bandwidth which is available.

5.1.2 Meteor Burst Communications

With the introduction of satellite communications many countries are tending to overlook this reliable communications media. The attraction for military users is the small foot print and short transmission duration leading to reduced probability of intercept communications for distances up to 2000 km. MBC systems typically use the low VHF frequency band from 40 to 55 MHz, but wider frequencies are useable.

In order to evaluate the feasibility of using MBC DSTO has been evaluating a link between Melbourne and Adelaide. Using a simple ARQ protocol the link achieves error free average data throughputs approaching those of the HF chirp modem. Simulations have shown that the application of advanced digital signal processing to the system will significantly increase the average throughput. The demonstrator being constructed by DSTO employs IBM PC computers to significantly reduce the cost of each installation.

5.2 Channel Modelling

This report has presented the performance of HF modems on a range of standard test channels as specified in the CCIR recommendations. While the specification of the channel is based on an understanding of the physics of a typical HF channel, there is some concern that this is not the best approach for the development and testing of modems. For example the current generation channel simulators do not allow exact modem comparisons, since the simulator will not recreate the same channel for repeated test runs. This can be achieved if relevant channel parameters are stored and then used to recreate the channel at a later date.

The Replay Simulator measures directly the distortion of a signal when it is transmitted over a channel. These distortions are stored and can be recalled and applied to any input signal at a later date. The result is that the replay simulator recreates the original channel allowing modem testing or channel measurement. The system will allow meaningful modem A versus modem B comparisons, which are directly related to actual HF radio channels. In addition the data base of stored channels can be used to design and test high performance modems.

6. Future Work

The modem development is still continuing. Currently there is on going research into:

AUTOMATIC REPEAT REQUEST (ARQ)

The current ARQ protocol has been developed for full duplex transmission with equal amounts of data in both directions. While this allows the greatest possible throughput it is not sufficiently adaptive. If there are differing traffic requirements in opposite directions it may be preferable to decrease the data rate in one direction, thereby making the link more robust. The ability to run different data rates in opposite directions is relatively simple provided that both data rates are derived from the same modem, eg TCM-16 300 bps transmit and TCM-16 2400 bps receive. In the short term it will not be possible to run rates from different modems in opposite directions.

While the capability of full duplex transmission will be realistically available in the near future, many systems will only be capable of half duplex operation, for example current ALE systems. This requires more modem development to ensure that the receiver does not need to reacquire the signal after each transmission and avoiding error bursts due to discontinuities in the error-control code.

CRYPTOGRAPHIC EQUIPMENT

The inclusion of cryptographic terminal equipment while the modem is using ARQ has not yet been tested. Investigations indicate that setting the crypto units to be clocked from the modem will not cause problems. This will allow the modem to clock out the data as it arrives, without the need for buffering. The only constraint is that the bit rate delivered to the terminal equipment will vary widely.

VERY ROBUST MODEMS

The success of the chirp modem leads the way for the design of even more robust modems - these modems could offer even lower data rates and be capable of working with high levels of distortion and interference. Another approach is to utilise the independent sidebands to double the available bandwidth. Finally, continuously changing the modem waveform will complicate signal intercept.

CHANNELISED MODEMS

The implementation of a channelised modem would offer a compromise between the simplicity of the parallel-tone modems and the performance of the single-tone modem. The first prototype has already been implemented, called the MCG-16, it demonstrated a channelised 16-tone modem implementing 75, 150, 300 and 600 bps. While the modem was not fully developed it showed performance advantages over the chirp modem at 75 bps and over the TCM-16 modem at 300 bps.

The DSTO range of enhanced parallel-tone modems use differential phase modulation this incurs a loss of nearly 3dB. Investigations have been undertaken to reduce this loss. The results to date have not been promising. The alternative is to introduce probe symbols into the signalling waveform, similar to those used in the MIL-STD single tone modem. While this increases the modem complexity it can overcome the 3dB differential loss.

It should be noted that the TCM-16 and 52-tone modems use an FFT to demodulate the incoming tones. While this is computationally very efficient the modems are vulnerable to large inband interferers. The hybrid modem will employ a channelised approach, making the modem considerably more robust, especially when combined with noise excision.

AUTOMATIC WAVEFORM DETECTION

Automatic waveform detection will be implemented in the near future. In this mode the modem will automatically identify the incoming waveform and adapt the modem parameters to demodulate it. The search will need to be reduced to a subset of all possible interleave depths to allow detection in a reasonable period of time. Functionally it will be similar to the 'Sync on Data' mode offered for the MIL-STD single-tone modem.

EVEREST

Automatic Link Establishment (ALE) offers automatic negotiation of the optimum communications frequency. Current ALE equipments do not monitor the traffic quality and therefore do not change frequencies when modem performance degrades. In addition the signalling waveform used to probe the channel rejects channels with small amounts of interference, while many modems are quite tolerant of small amounts of interference. Clearly these short comings could be overcome if the ALE equipment used the desired modem signal to monitor the channel conditions. This can be achieved using the EVEREST technique patented by DSTO several years ago. Research will continue into the use of EVEREST to monitor modem performance enabling the selection of the optimum communications channel. The use of error-control codes requires the implementation of an EVEREST capable of predicting the bit error rate after the error-correcting code. This has been successfully simulated and should be implemented in the very near future.

ADAPTION CONTROL

DSTO has implemented a range of modems to cover a wide range of channel conditions. In addition the modems have been designed to allow rapid reconfiguration. The adaption strategy is still being developed via simulations and is based on the TCM-16 modem. Rate adaption will be handled by a knowledge-based controller with inputs from the coded EVEREST and the ARQ sceheme (specifically the number of packets that require retransmission). More information can be found in The DORIC Program: Adaptive Radio.

SUB-OPTIMAL TRELLIS DECODERS

Currently the modems employ Viterbi maximum-likelihood trellis decoders. While these offer the best possible performance they are computationally expensive, limiting the length of the code that can be implemented. There are sub-optimal decoding techniques that will allow more powerful error-control codes to be implemented. The gain due to the more powerful codes could out weigh the loss in the sub-optimal decoding.

BLOCK CODED MODULATION

Early investigations indicated that the use of TCM lead to the greatest coding gain for practical HF data modems. This was largely due to the comparatively poor performance of hard decision decoded block codes which are designed primarily for AWGN channels. Recent developments in Block Coded Modulation (BCM) reveal that the difference may not be that significant. Several schemes allow soft decision decoding using iterative approaches. While other schemes have been specifically designed to operate on fading channels. In addition there are distinct advantages to the use of coding schemes that have a well defined start and end point, for example the half duplex modem could easily be constructed so that the transmission burst forms a complete error-control block. A final advantage may come from the high data rates of typical block codes. DSTO intends to investigate the application of these new BCM schemes for special modem applications.

ITERATIVE DECODER

Recent work in the area of iterative decoding has shown significant promise. Very powerful error-control codes can be implemented relatively cheaply. In addition the codes are inherently long, so that interleaver delays are provided automatically. Finally the codes can be iteratively decoded enabling optimum use of the available computing resources. Questions remain as to the merit of the codes on fading channels with non-Gaussian noise.

7.   CONCLUSIONS

The modems that have been implemented have overcome many of the problems associated with current MIL-STD HF modems. The modems offer higher data rates, greater availability, lower transmit power and are designed to be robust on the HF channel. In addtion the modems have been designed to allow rapid reconfiguration to track changing channel conditions. While the truly adaptive modem has still not been demonstrated, this will be given high priority and should be available during 1995.

Research planned in the near future will further enhance the performance of the modems and the adaption strategy used to control the modems. The result will be modems that are able to support the reliable communications required by the DORIC program.

DSTO has already commenced a program of work to extend the ideas developed for the HF modems to other frequency bands. The meteor burst and VHF troposcatter equipments will also provide reliable communications.

The DORIC Program : HF Modem Technology

Martin C Gill

DSTO-RR-0041

DISTRIBUTION LIST

Number of Copies

DEPARTMENT OF DEFENCE

Defence Science and Technology Organisation

Chief Defence Scientist and members of the	)	1 shared copy
DSTO Central Office Executive	)	for circulation
Counsellor, Defence Science, London		(Document Control sheet)
Counsellor, Defence Science, Washington		(Document Control sheet)
Scientific Adviser - POLCOM		1
Senior Defence Scientific Adviser		1
Assistant Secretary Scientific Analysis		1
Director, Aeronautical & Maritime Research Laboratory		1

Electronics and Surveillance Research Laboratory

Director, Electronics and Surveillance Research Laboratory	1
Chief, Communications Division	1
Chief, Information Technology Division	1
Research Leader, Military Communications	1
Research Leader, Secure Communications	1
Research Leader, Command, Control, Communications	1
Research Leader, Military Computing Systems	1
Research Leader, Command, Control and Intelligence Systems	1
Head, Switched Networks	1
Head, Communications Integration	1
Martin Gill, Ag Head Radio Networks	3

Navy Office

Navy Scientific Adviser (NSA)	1

Army Office

Scientific Adviser, Army (SA-A)	1

Air Office

Air Force Scientific Adviser (AFSA)	1

Headquarters Australian Defence Force

Development Division

Director General, Force Development (Joint)	1
Director General, Force Development (Land)	1
Director General, Force Development (Air)	1
Director General, Force Development (Sea)	1
Director Communications Development	1
Director Communications and Information Systems Policies and Plans	1

Operations Division

Director General, Joint Communicaions and Electronics	1

Force Development and Analysis Division

Assistant Secretary, Project Development	1

Defence Materiel Division

Director General, Joint Projects Management Branch	1
Assistant Secretary, Communications and Info. Systems Eng. Branch	1
Director, Communications Engineering Development	1

Defence Intelligence Orginisation

Deputy Director, Defence Intelligence Orgainisation	1

Defence Signals Directorate

Director, Defence Signals Directorate	1

Libraries and Information Services

Defence Central Library - Technical Reports Centre	1
Manager Document Exchange Centre (MDEC) (for retention)	1
Defence Science and Technology Organisation Salisbury, Research Library	2

Spares

Defence Science and Technology Organisation Salisbury, Research Library	31

<div align="center">

Department of Defence

DOCUMENT CONTROL DATA SHEET

</div>

1. Page Classification
UNCLASSIFIED
2. Privacy Marking/Caveat (of document)
N/A

3a. AR Number	3b. Laboratory Number	3c. Type of Report	4. Task Number	
AR-009-232	DSTO-RR-0041	Research Report	ADF 90/010.2	

5. Document Date	6. Cost Code	7. Security Classification	8. No of Pages	20

10. Title

The DORIC Program : HF Modem Technology

7. Security Classification

* [U] [U] [U]

Document   Title   Abstract

S (Secret) C (Confi) R (Rest) U (Unclas

* For UNCLASSIFIED docs with a secondary distribution LIMITATION, use (L) in document box.

9. No of Refs

11. Author(s)	12. Downgrading/Delimiting Instructions
Martin C Gill	N/A

13a. Corporate Author and Address	14. Officer/Position responsible for
Electronics & Surveillance Research Laboratory PO Box 1500, Salisbury SA 5108	Security: ....SOESRL... Downgrading: ....CCD..
13b. Task Sponsor DJFD(J)	Approval for Release: ...CCD...

15. Secondary Release Statement of this Document

Approved for public release

16a. Deliberate Announcement

No limitation

16b. Casual Announcement (for citation in other documents)

[X] No Limitation   [   ] Ref. by Author, Doc No. and date only

17. DEFTEST Descriptors	18. DISCAT Subject Codes
DORIC Program HF Data Modems	

19. Abstract

This report describes the HF data modem work undertaken at DSTO as part of the DORIC program.